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EFFECT OF WOODY VEGETATION ON HYDRAULIC CONDUCTIVITY AT VARIOUS LEVEE SYSTEMS USING NUMERICAL MODELS

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Summary. This paper provides the results of varying the hydraulic conductivity in a root zone of woody vegetation on levees. Four levees were used in the analyses.

1 INTRODUCTION

The objective of this study was to provide a better understanding of the influence of a root system from woody vegetation on hydraulic conductivity of soils in levee systems. By evaluating changes in hydraulic conductivity, conditions for seepage, specifically underseepage and piping, can be identified. To meet this objective, seepage analyses using the finite element method were conducted for representative levees in Sacramento, CA; Burlington, WA; Albuquerque, NM; and Portland, OR. A levee cross section for each of these levee systems was constructed using the Groundwater Modeling System[1] to support both two-dimensional (2-D) steady-state and transient computations using Seep2D[2]. Three-dimensional (3-D) solutions were also derived by extruding these 2-D cross sections to form a 3-D mesh and then running a parallel 3-D groundwater program using high performance computing.

For each levee cross section, a rectangular block representing a root zone was placed at different locations on the levee profile. The root zone was estimated from geophysical surveys[3] to be approximately 6 ft × 5 ft in size for many tree types. To quantify and bound the effect of a tree, the original saturated hydraulic conductivity assigned to the root zone was multiplied by a factor, β, where $0.01 \le \beta \le 100.0$. Seep2D was run with values of $\beta = 0.01, 0.1, 1, 10$, and 100 for the different root zone locations, and the differences in total head, gradient, velocity, and pore pressure were observed. When $\beta = 1$, no tree was present. Both steady-state and transient results were obtained for river levels representing flood stages for each levee system.

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14. ABSTRACT

The objective of this study was to provide a better understanding of the influence of a root system from woody vegetation on hydraulic conductivity of soils in levee systems. By evaluating changes in hydraulic conductivity, conditions for seepage, specifically underseepage and piping,can be identified. To meet this objective, seepage analyses using the finite element method were conducted for representative levees in Sacramento, CA; Burlington, WA; Albuquerque, NM; and Portland, OR. A levee cross section for each of these levee systems was constructed using the Groundwater Modeling System1 to support both two-dimensional (2-D) steady-state and transient computations using Seep2D2. Three-dimensional (3-D) solutions were also derived by extruding these 2-D cross sections to form a 3-D mesh and then running a parallel 3-D groundwater program using high performance computing.

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2 DESCRIPTION OF THE LEVEES

2.1 Sacramento, CA

Fig. 1 shows the cross section from the Pocket Levee along the Sacramento River with the different soil layers, and Fig. 2 shows the placement of trees on the levee for analysis purposes. The crest of the levee is at el 32 ft. The elevation of the river was set to 23 ft, 26 ft, and 29 ft for steady-state flow analyses. The elevation of the water level on the landside was set to 12 ft at a distance of 2,000 ft downstream of the levee. For the transient analysis, the hydrograph shown in Fig. 3 was used.

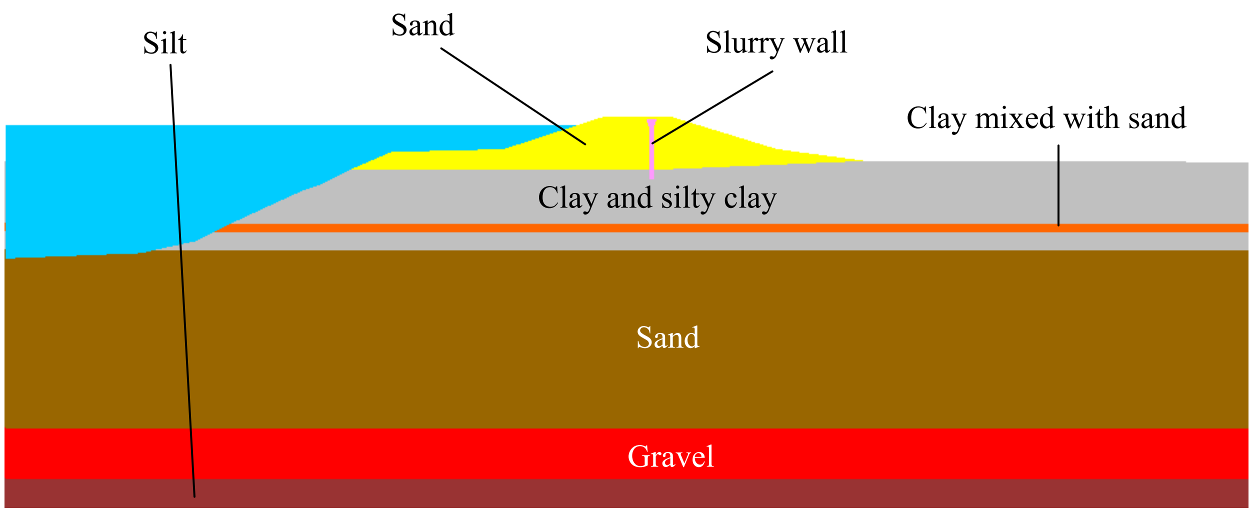

Figure 1: Cross section of Pocket Levee, Sacramento, CA

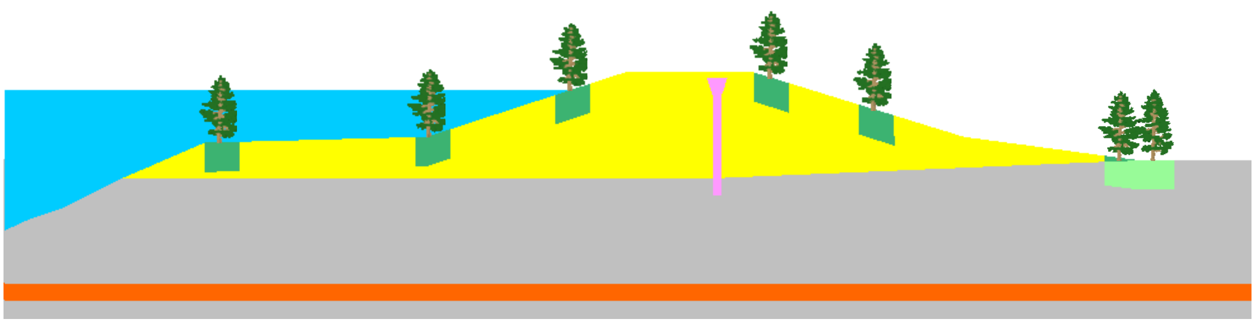

Figure 2: Tree placement for Pocket Levee, Sacramento, CA

As shown in Table 1, the hydraulic conductivities for these soil layers vary four orders of magnitude.

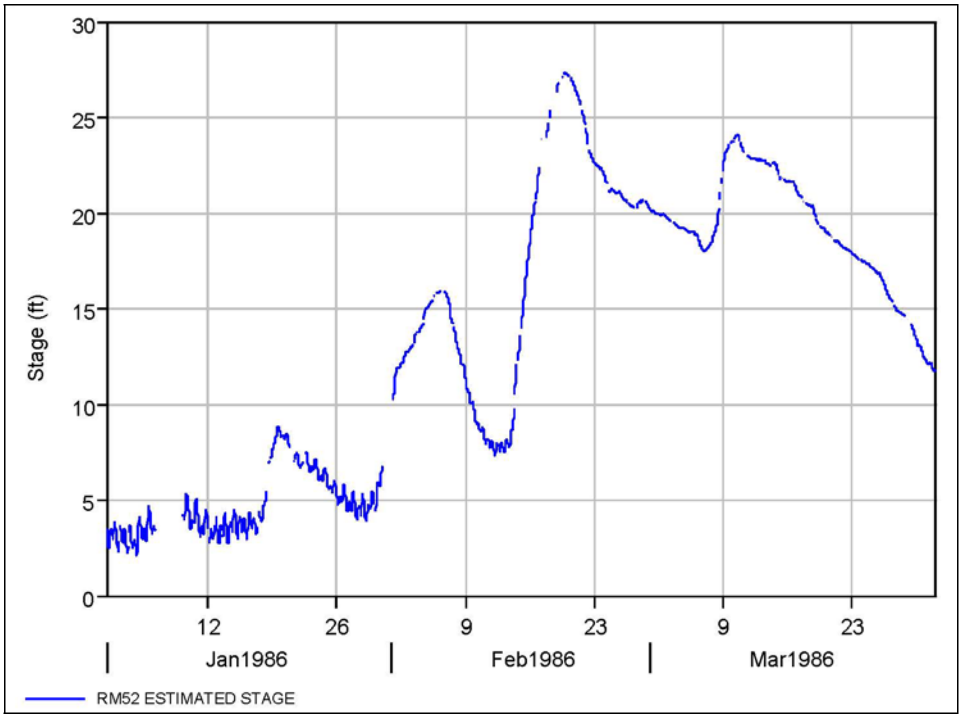

Figure 3: Hydrograph for 1986 flood on Sacramento River at River Mile (RM) 52

Material	k_H (cm/sec)	k_H (ft/day)	k_V (cm/sec)	k_V (ft/day)
Sand in the levee	8.00×10^{-3}	22.7	2.00×10^{-3}	5.67
Clay and silty clay	8.00×10^{-4}	2.27	2.00×10^{-4}	0.568
Clay mixed with sand	3.00×10^{-5}	0.085	1.00×10^{-5}	0.0283
Sand in the aquifer	8.00×10^{-2}	226.7	2.00×10^{-2}	56.7
Gravel	2.00×10^{-2}	56.7	2.00×10^{-2}	56.7
Silt	1.00×10^{-4}	0.283	1.00×10^{-4}	0.283
Slurry wall	1.00×10^{-6}	0.00283	1.00×10^{-6}	0.00283

Table 1: Hydraulic conductivities used for different material properties for Pocket Levee

2.2 Burlington, WA

Fig. 4 shows the cross section for the levee along the Skagit River in Burlington, WA. The elevation of the river for steady-state analysis was set to 38.7 ft, which is the highest stage on the hydrograph used in the transient analysis as shown in Fig. 5 for the 1995 flood. The elevation of the water level on the landside was set to 32.2 ft. Table 2 shows the hydraulic conductivities for this cross section.

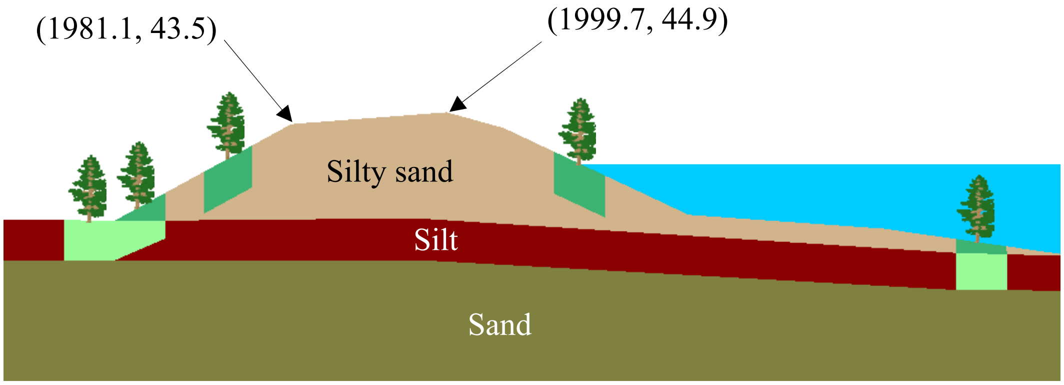

Figure 4: Cross section with material types and tree placements for levee in Burlington, WA

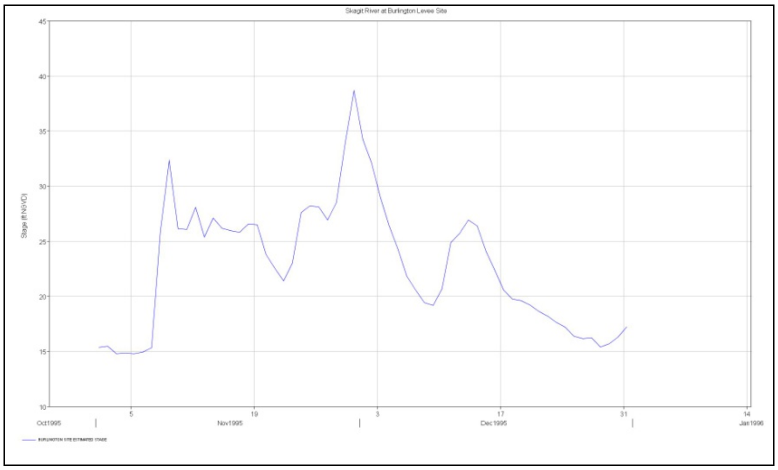

Figure 5: Hydrograph for the 1995 Burlington, WA flood

Material	k_H (cm/sec)	k_H (ft/day)	k_V (cm/sec)	k_V (ft/day)
Silty sand	1.17×10^{-3}	3.32	1.17×10^{-3}	3.32
Silt	2.00×10^{-3}	5.67	1.00×10^{-3}	2.83
Sand	4.00×10^{-2}	113.39	4.00×10^{-2}	113.39

Table 2: Hydraulic conductivities for soils used in model for Burlington, WA

2.3 Portland, OR

Fig. 6 shows the geometry, tree placement, and soil layers for the levee along the Columbia River in Portland, OR. The elevation of the river was set to 29.6 ft for the steady-state flow analyses, and the elevation of the water level on the landside was set to 25.0 ft for this cross section. A hydrograph for a Columbia River flood was selected for the transient analysis. Table 3 gives the hydraulic conductivities used in the numerical analysis.

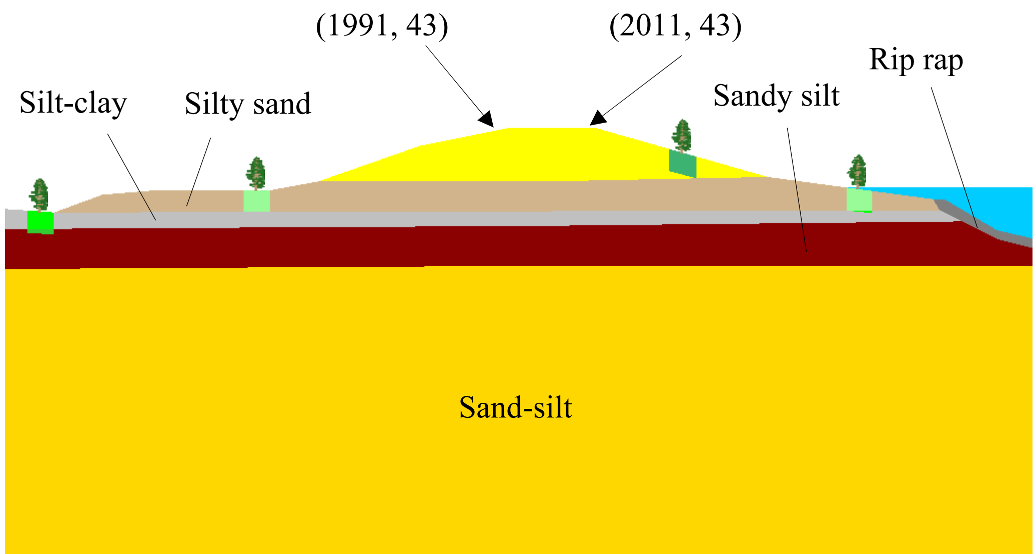

Figure 6: Cross section with material types and placements for levee along Columbia River in Portland, OR

Material	k_H (cm/sec)	k_H (ft/day)	k_V (cm/sec)	k_V (ft/day)
Sand	1.94×10^{-2}	54.9	9.66×10^{-3}	27.4
Silty sand	1.94×10^{-3}	5.5	9.52×10^{-4}	2.7
Silt-clay	7.05×10^{-5}	0.2	3.52×10^{-5}	0.1
Sandy silt	1.76×10^{-4}	0.5	1.06×10^{-4}	0.3
Sand-silt	1.94×10^{-3}	5.5	9.52×10^{-4}	2.7
Rip rap	0.645	1828.8	0.645	1828.8

Table 3: Hydraulic conductivities for material used for model along Columbia River in Portland, OR

2.4 Albuquerque, NM

Fig. 7 shows the geometry, tree placement, and soil layers for a levee along the Rio Grande River in Albuquerque, NM. The elevation of the river was set to 4989.0 ft and 4992.0 ft for steady-state flow analyses, and the elevation of the water level on the landside was set to 4985.0 ft for this cross section. A hydrograph of the 1942 flood was selected for the transient analysis. Table 4 gives the hydraulic conductivities used in the numerical analysis.

3 ANALYSIS

The allowable factor of safety for use in evaluations and design of seepage control measures should correspond to an exit gradient at the toe of the levee of $i = 0.5$[4]. The exit gradient is the

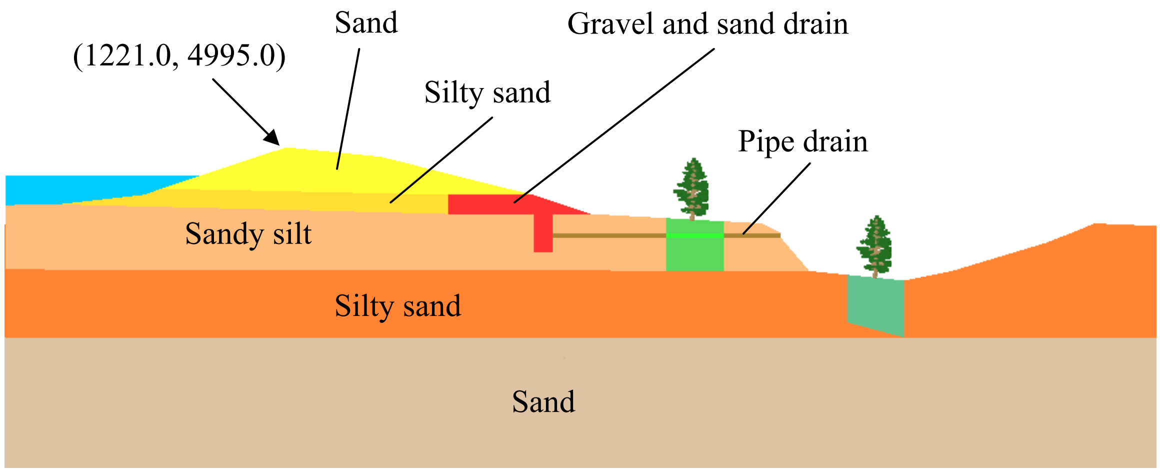

Figure 7: Cross section with material types and tree placements for levee in Albuquerque, NM

Material	k_H (cm/sec)	k_H (ft/day)	k_V (cm/sec)	k_V (ft/day)
Sand in the levee	3.00×10^{-3}	8.50	3.00×10^{-3}	8.50
Silty sand in the levee	1.00×10^{-4}	0.283	1.00×10^{-4}	0.283
Sandy silt in the blanket	1.00×10^{-5}	0.0283	1.00×10^{-5}	0.0283
Silty sand in the aquifer	3.00×10^{-4}	0.850	3.00×10^{-4}	0.850
Sand in the aquifer	6.00×10^{-3}	17.0	6.00×10^{-3}	17.0
Toe drain	1.00×10^{-3}	2.83	1.00×10^{-3}	2.83
Pipe drain	1.00×10^{-2}	28.3	1.00×10^{-2}	28.3

Table 4: Hydraulic conductivities for soils used in model for Albuquerque, NM

change in total head per unit length at the ground surface where water exits. The critical exit gradient is

$$i_c = \frac{\gamma_{ss}}{\gamma_w} - 1 \qquad (1)$$

where i_c is the critical gradient, γ_{ss} is the density of saturated soil, and γ_w is the density of water. Table 5 gives values of exit gradient for values of β for tree placements for the levees considered. Exit gradients were computed at the toe for the Pocket and Burlington levees, the lower toe for the Portland levee, and the bottom of the dewatered drainage ditch for the Albuquerque levee. Transient results are highlighted in yellow. The use of β presents a range of exit gradients for different soil conditions near the tree as compared with away from the tree. Field measurement of hydraulic conductivity then gives details on what the actual value of β is for a given site.

	β = 0.001	β = 1	β = 100
Pocket Levee with Sacramento River at el 29 ft – Exit gradients calculated at toe			
Tree beyond the toe	0.49	0.33	0.01
Tree on the toe	0.24	0.33	0.03
Tree midway on the steeper landside slope	0.33	0.33	0.33
Tree near the top of the landside	0.33	0.33	0.33
Tree at the river height on the riverside	0.33	0.33	0.33
Tree at the change in slope on the riverside	0.33	0.33	0.33
Tree near the end of the levee sand on the riverside	0.33	0.33	0.33
Pocket Levee with Sacramento River at el 26 ft – Exit gradients calculated at toe			
Tree beyond the toe	0.43	0.28	0.00
Tree beyond the toe – Transient	0.00	0.00	0.00
Tree on the toe	0.19	0.28	0.02
Tree midway on the steeper landside slope	0.28	0.28	0.28
Tree near the top of the landside	0.28	0.28	0.28
Tree at the river height on the riverside	0.28	0.28	0.28
Tree at the change in slope on the riverside	0.28	0.28	0.28
Tree near the end of the levee sand on the riverside	0.28	0.28	0.28
Levee in Burlington, WA, with Skagit River at el 38.7 ft – Exit gradients calculated at toe			
Tree beyond the toe	1.09	0.81	0.11
Tree beyond the toe – Transient	0.99	0.74	0.11
Tree on the toe	0.59	0.81	0.22
Tree nearly halfway to the top of the levee on the landside	0.81	0.81	0.81
Tree nearly halfway to the top of the levee on the riverside	0.80	0.81	0.82
Tree near the heel on the riverside	0.80	0.81	0.87
Levee in Portland, OR, with Columbia River at el 29.6 ft – Exit gradients calculated at lower toe			
Tree beyond the lower toe	0.84	0.69	0.11
Tree beyond the lower toe – Transient	0.64	0.53	0.13
Tree just beyond the upper toe of the levee	0.68	0.69	0.69
Tree nearly halfway to the top of the levee on the riverside	0.69	0.69	0.69
Tree at the water level on the riverside	0.68	0.69	0.69

	$\beta = 0.001$	$\beta = 1$	$\beta = 100$
Levee in Albuquerque, NM, with Rio Grande River at el 4992 ft – Exit gradients calculated at bottom of dewatered drainage ditch			
Tree near the toe	1.00	0.99	0.99
Tree at the bottom of the ditch	1.11	0.99	0.16
Levee in Albuquerque, NM, with Rio Grande River at el 4989 ft – Exit gradients calculated at bottom of dewatered drainage ditch			
Tree near the toe	0.86	0.86	0.86
Tree at the bottom of the ditch	0.98	0.86	0.63
Tree at the bottom of the ditch – Transient	0.85	0.74	0.12

Table 5: Exit gradient for tree locations on each levee site for different values of β

4 CONCLUSIONS

Exit gradients from both the steady state analyses and the transient analyses are reported in Table 5 for each levee. After reviewing the analyses, the following conclusions were realized: (1) A tree placed on or just beyond the toe and at the bottom of a dewatered drainage ditch of a levee significantly changes the exit gradient. (2) Trees placed at other points along the levee have no impact on the exit gradient at the toe, assuming the absence of long-reaching defects from the roots. (3) The higher the river levels, the greater the exit gradients. (4) The transient solutions generally yielded lower exit gradients than the steady-state runs.

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